US010361586B2

(12) **United States Patent**
Chong et al.

(10) **Patent No.: US 10,361,586 B2**
(45) **Date of Patent: Jul. 23, 2019**

(54) **METHOD OF WIRELESSLY TRANSFERRING POWER**

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(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 688 days.

(21) Appl. No.: **14/983,372**

(22) Filed: **Dec. 29, 2015**

(65) **Prior Publication Data**

US 2017/0187238 A1 Jun. 29, 2017

(51) **Int. Cl.**

H02J 50/10 (2016.01)
H02J 50/50 (2016.01)
H02J 7/02 (2016.01)
H02J 50/12 (2016.01)

(52) **U.S. Cl.**

CPC ***H02J 50/10*** (2016.02); ***H02J 7/025*** (2013.01); ***H02J 50/12*** (2016.02); ***H02J 50/50*** (2016.02)

(58) **Field of Classification Search**

CPC H02J 7/02; H02J 7/025
See application file for complete search history.

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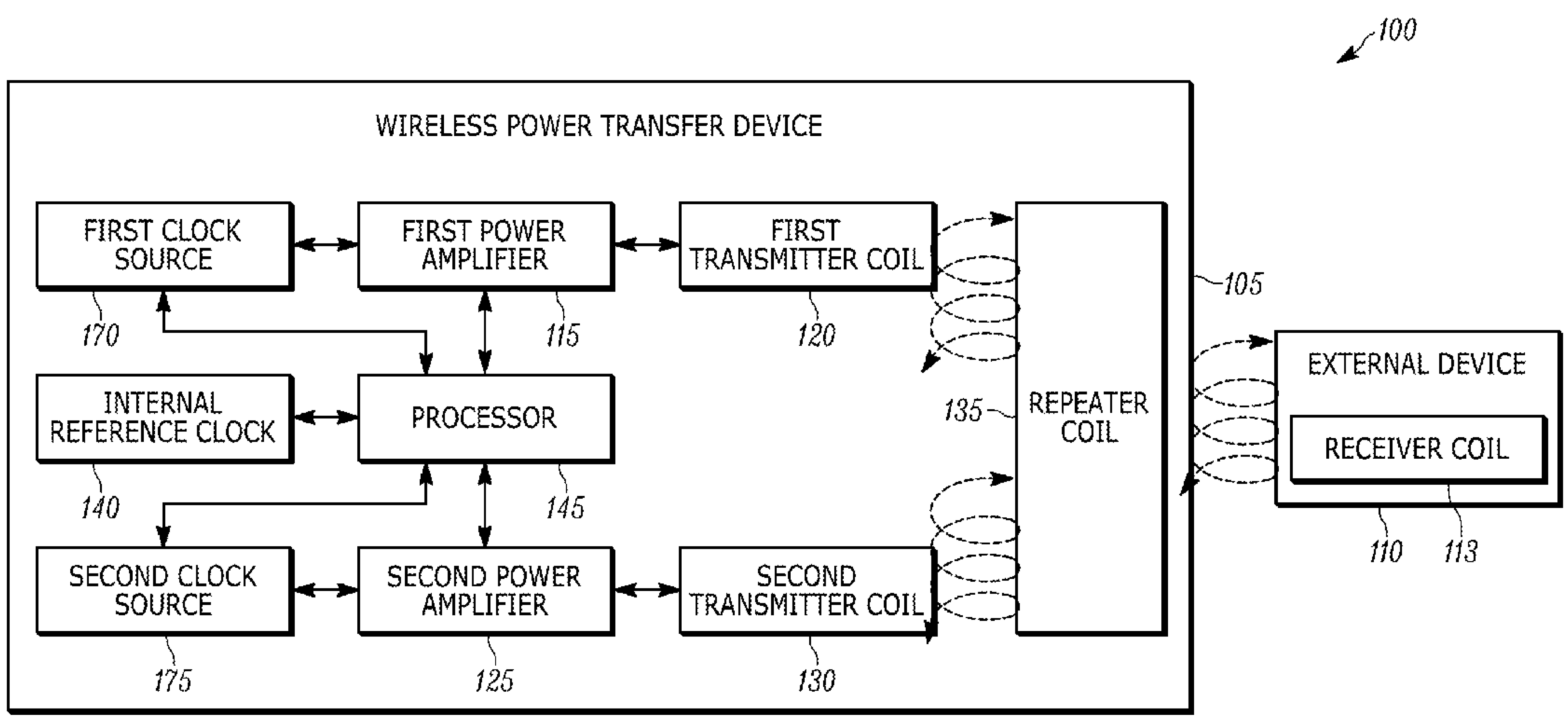
(57) **ABSTRACT**

A wireless power transfer device including a first power amplifier configured to generate a first drive signal, a second power amplifier configured to generate a second drive signal, a first transmitter coil configured to generate a first magnetic field having a first magnitude in response to receiving the first drive signal, and a second transmitter coil configured to generate a second magnetic field having a second magnitude in response to receiving the second drive signal. The wireless power transfer device also includes a

(Continued)



repeater coil magnetically coupled to the first transmitter coil and the second transmitter coil, and configured to generate a third magnetic field having a third magnitude. The third magnitude is greater than the first magnitude and greater than the second magnitude. The repeater coil is configured to magnetically transfer power to an external device.

25 Claims, 6 Drawing Sheets

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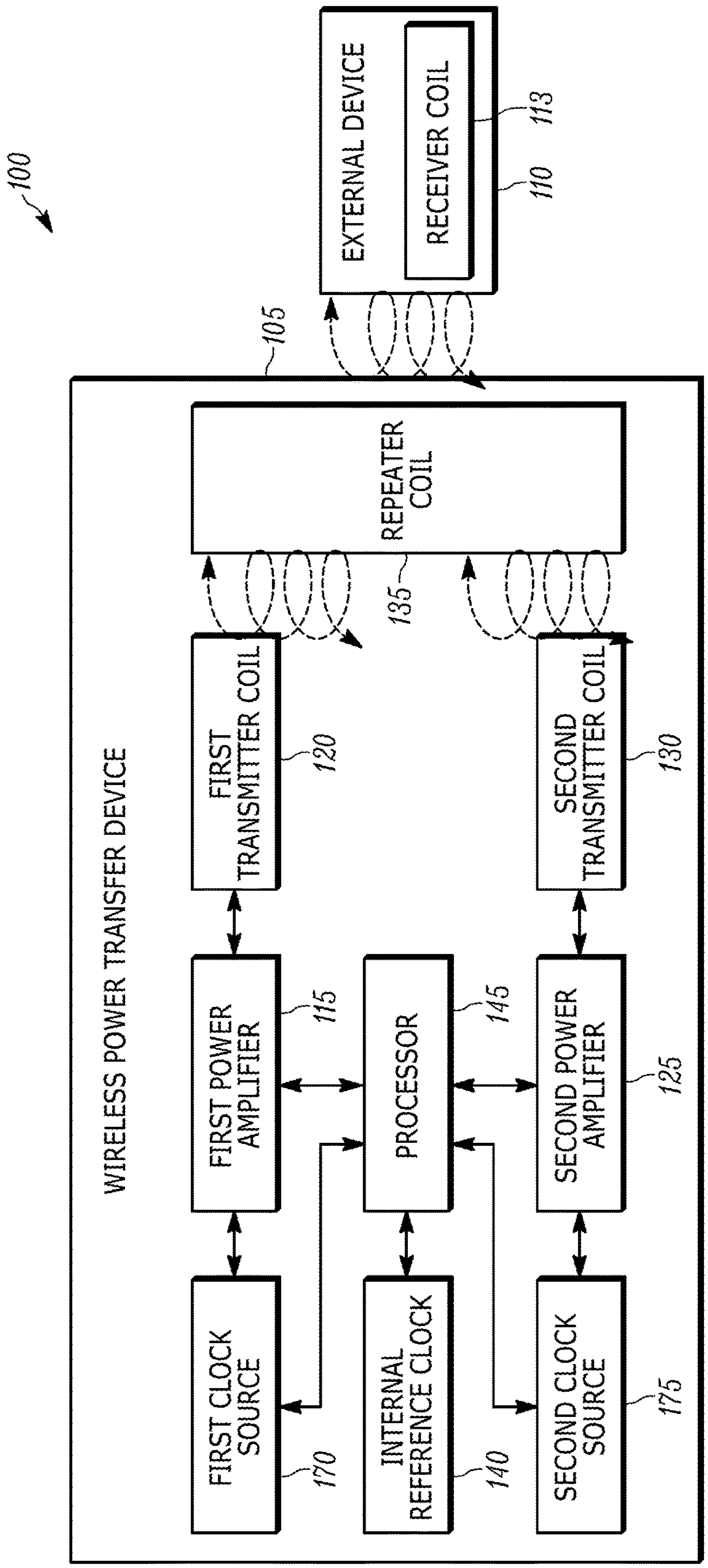
100
EXTERNAL DEVICE
RECEIVER COIL
113
110
105
WIRELESS POWER TRANSFER DEVICE
REPEATER COIL
135
FIRST TRANSMITTER COIL
120
SECOND TRANSMITTER COIL
130
FIRST POWER AMPLIFIER
115
PROCESSOR
145
SECOND POWER AMPLIFIER
125
FIRST CLOCK SOURCE
170
INTERNAL REFERENCE CLOCK
140
SECOND CLOCK SOURCE
175

FIG. 1

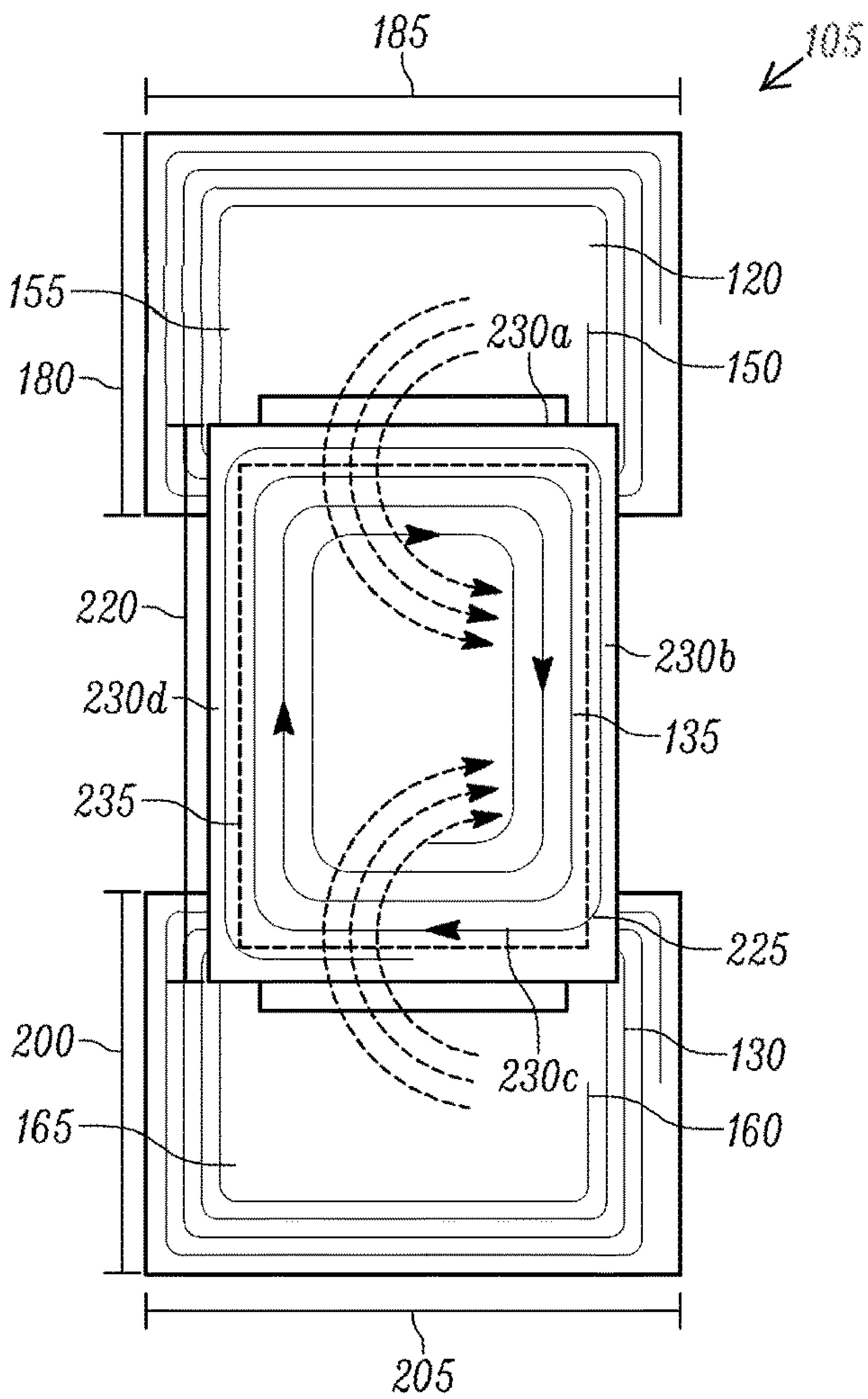
185
105
120
155
230a
150
180
220
230b
230d
135
235
225
200
130
230c
165
160
205

FIG. 2A

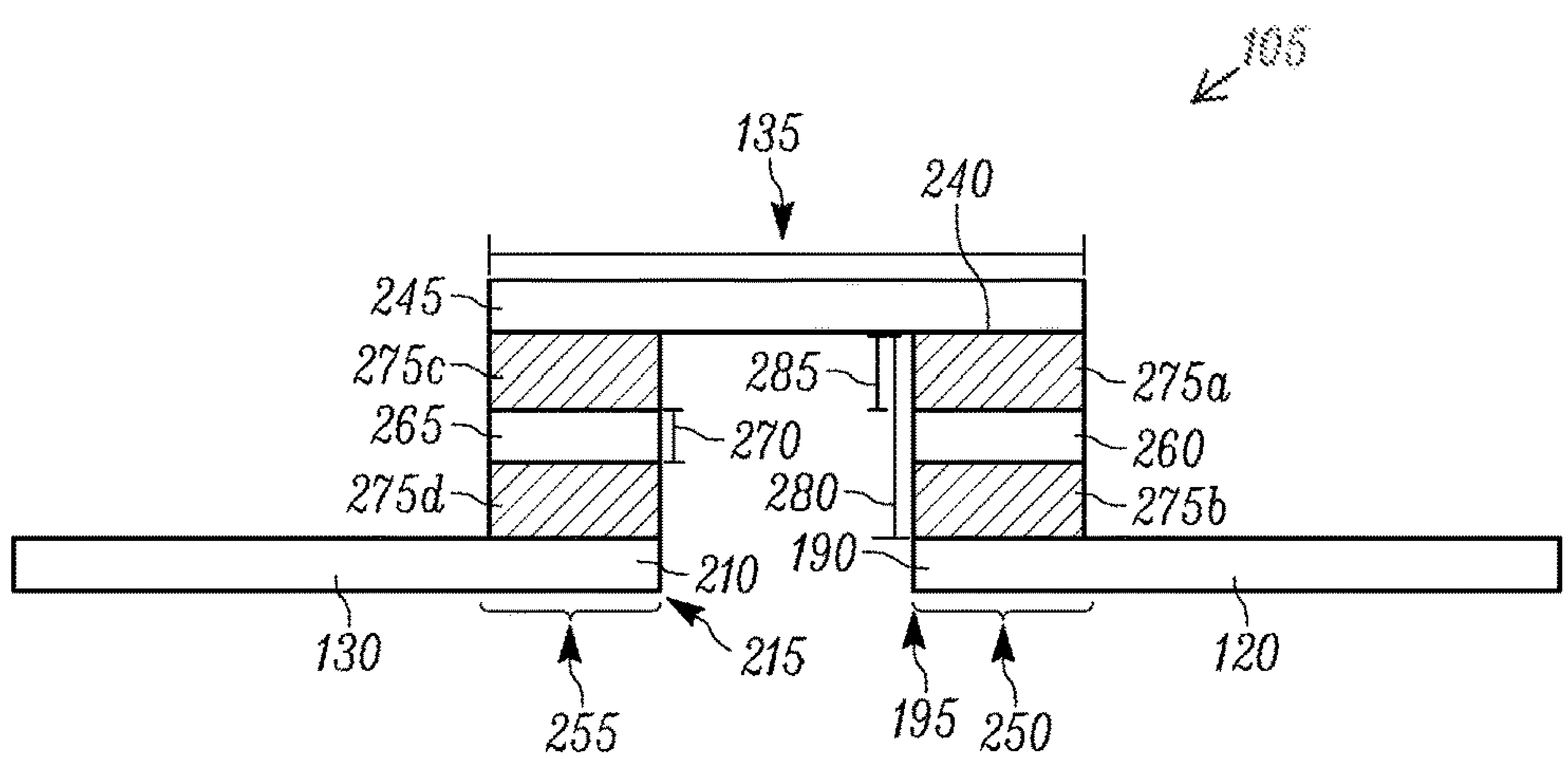
105
135
240
245
275c
285
275a
265
270
260
275d
280
275b
190
210
130
215
120
255
195
250

FIG. 2B

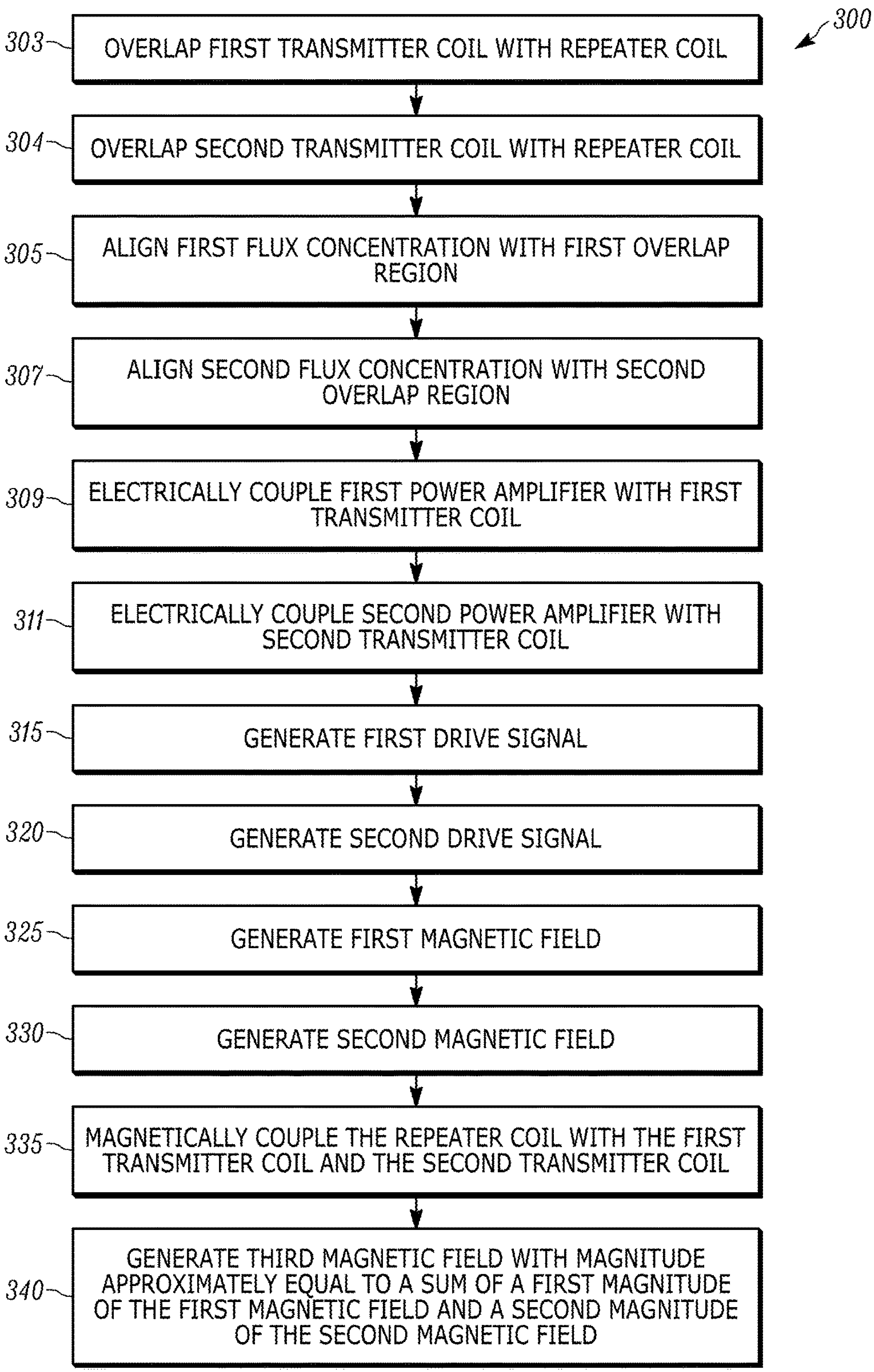
300
303
OVERLAP FIRST TRANSMITTER COIL WITH REPEATER COIL
304
OVERLAP SECOND TRANSMITTER COIL WITH REPEATER COIL
305
ALIGN FIRST FLUX CONCENTRATION WITH FIRST OVERLAP REGION
307
ALIGN SECOND FLUX CONCENTRATION WITH SECOND OVERLAP REGION
309
ELECTRICALLY COUPLE FIRST POWER AMPLIFIER WITH FIRST TRANSMITTER COIL
311
ELECTRICALLY COUPLE SECOND POWER AMPLIFIER WITH SECOND TRANSMITTER COIL
315
GENERATE FIRST DRIVE SIGNAL
320
GENERATE SECOND DRIVE SIGNAL
325
GENERATE FIRST MAGNETIC FIELD
330
GENERATE SECOND MAGNETIC FIELD
335
MAGNETICALLY COUPLE THE REPEATER COIL WITH THE FIRST TRANSMITTER COIL AND THE SECOND TRANSMITTER COIL
340
GENERATE THIRD MAGNETIC FIELD WITH MAGNITUDE APPROXIMATELY EQUAL TO A SUM OF A FIRST MAGNITUDE OF THE FIRST MAGNETIC FIELD AND A SECOND MAGNITUDE OF THE SECOND MAGNETIC FIELD

FIG. 3

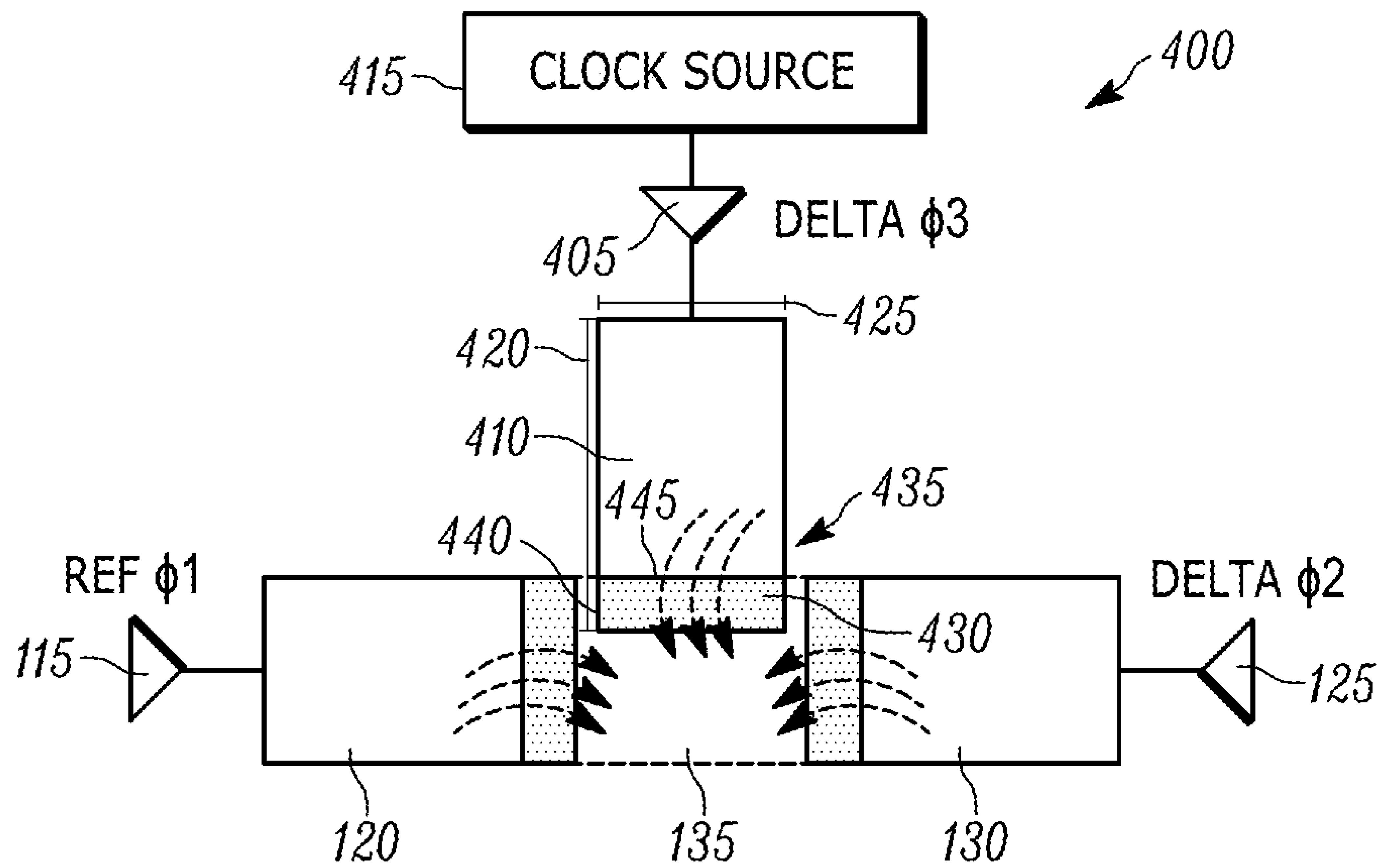
CLOCK SOURCE
415
400
DELTA ϕ3
405
425
420
410
435
445
440
REF ϕ1
DELTA ϕ2
430
115
125
120
135
130

FIG. 4

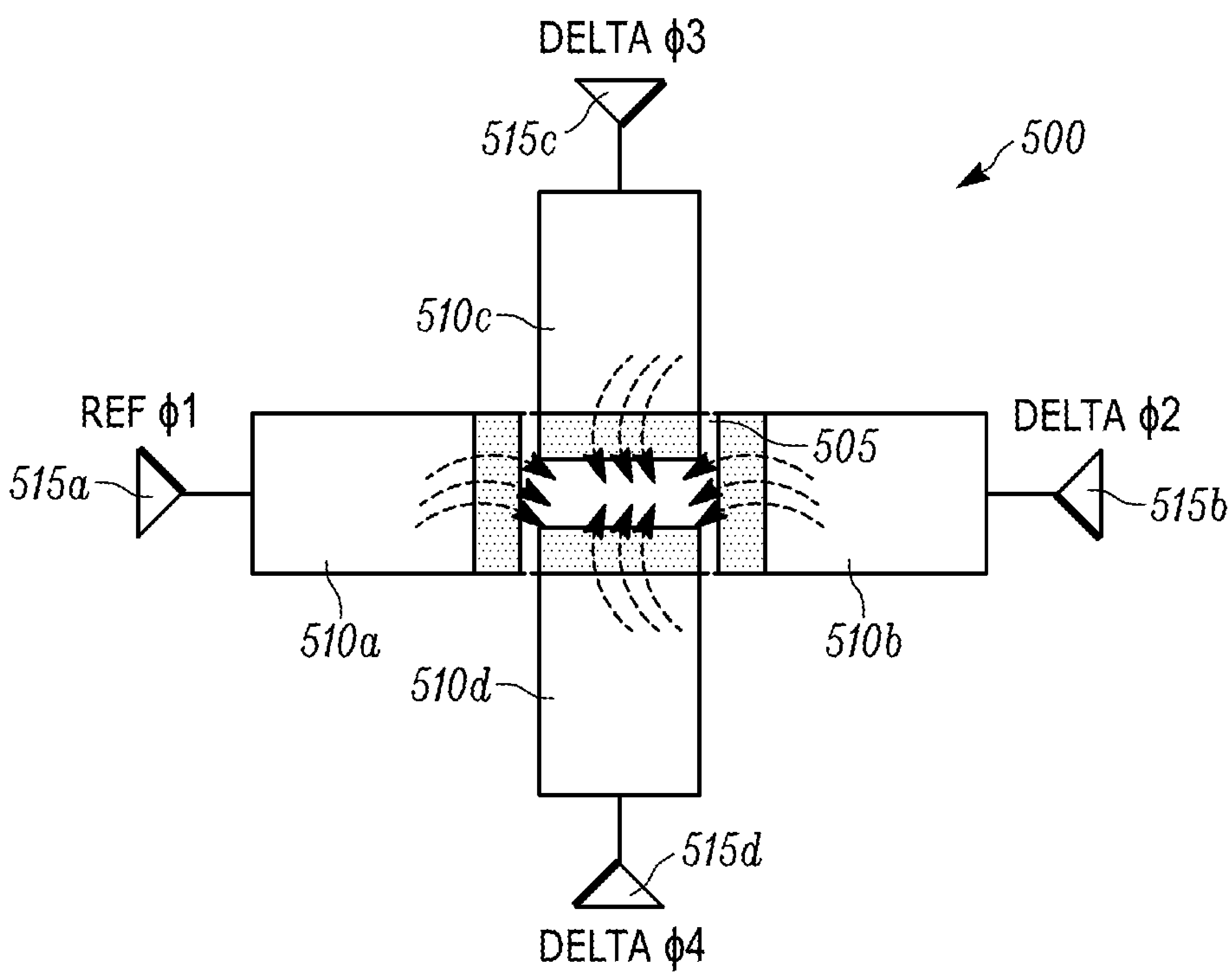
DELTA ϕ3
515c
500
510c
REF ϕ1
DELTA ϕ2
505
515a
515b
510a
510b
510d
515d
DELTA ϕ4

FIG. 5

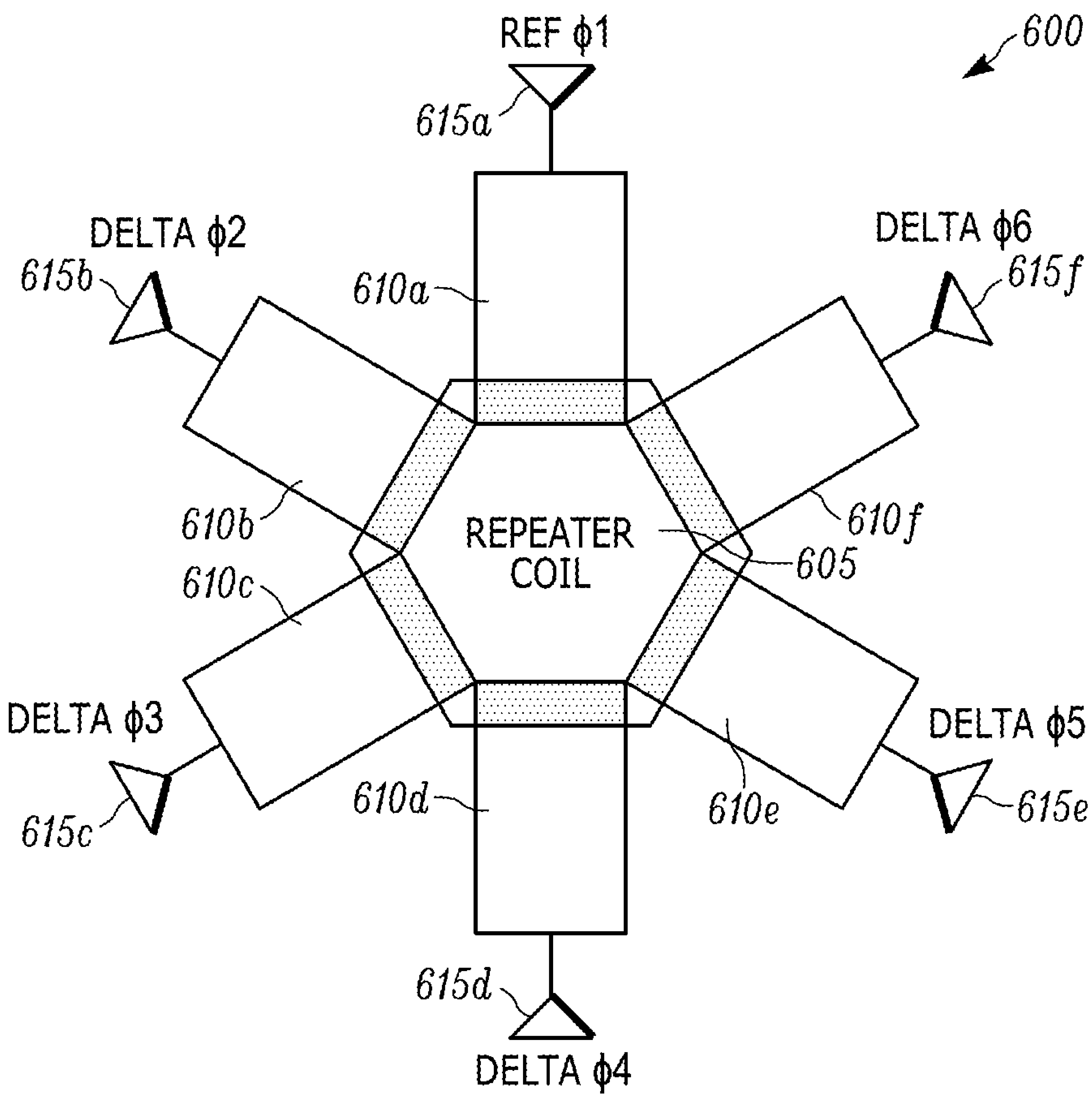
600
REF ϕ1
615a
DELTA ϕ2
615b
610a
DELTA ϕ6
615f
610b
REPEATER
COIL
610f
605
610c
DELTA ϕ3
615c
610d
610e
DELTA ϕ5
615e
615d
DELTA ϕ4

FIG. 6

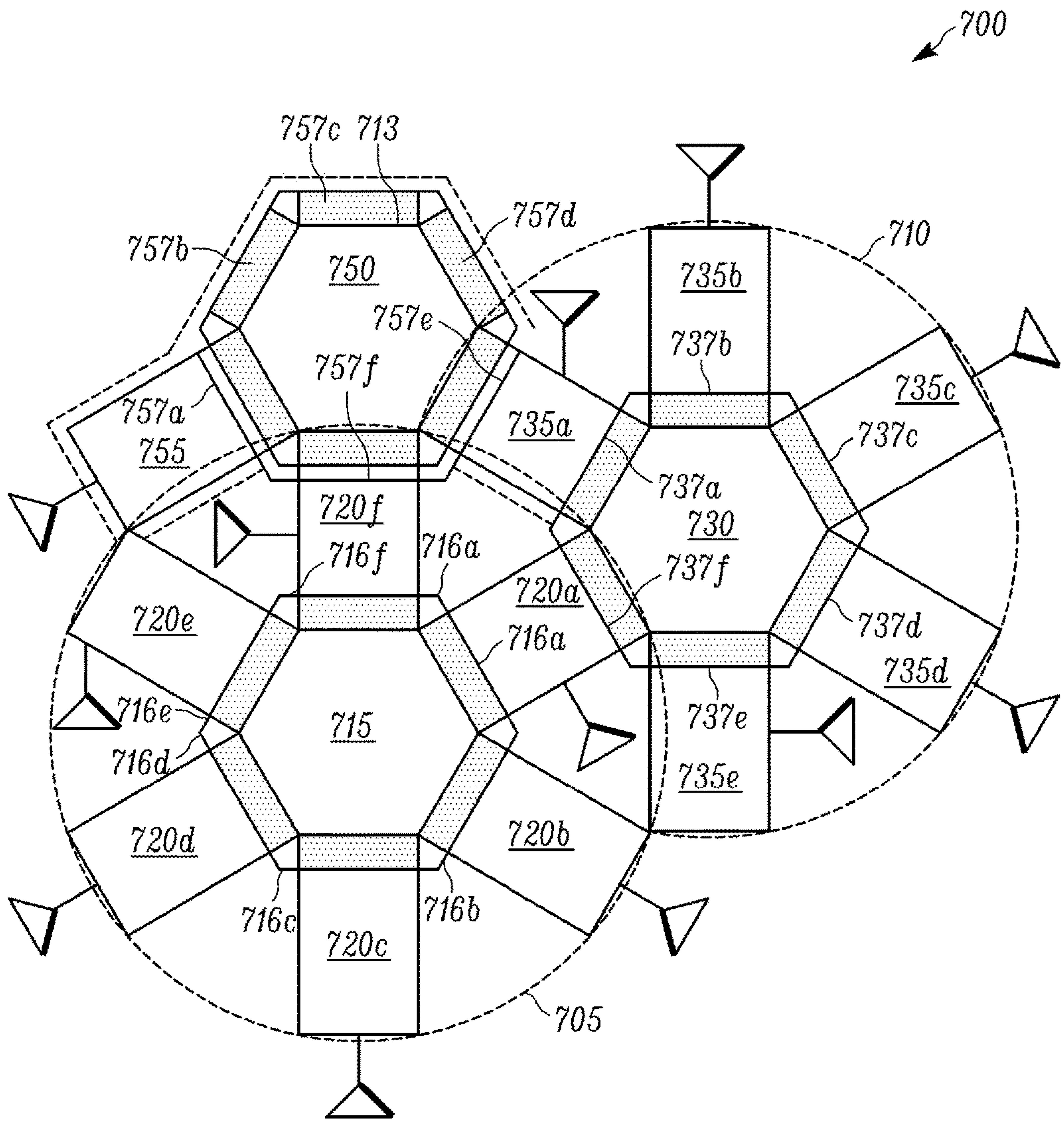
700
757c
713
757d
757b
750
710
735b
757e
737b
757f
735c
757a
735a
755
737c
737a
720f
730
716f
716a
737f
720a
720e
716a
737d
735d
737e
716e
715
716d
735e
720d
720b
716c
716b
720c
705

FIG. 7

METHOD OF WIRELESSLY TRANSFERRING POWER

BACKGROUND OF THE INVENTION

Interest for wireless power transfer has been growing recently. Additionally, there are various applications for wireless power transfer such as, for example, charging of batteries in small electronic devices (e.g., smart telephones, tablet computers, and the like), electric vehicles, and/or other electronic devices. Wireless power transfer (WPT) may be achieved in a number of ways. One wireless power transfer technology is magnetic-resonance power transfer.

BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWINGS

The accompanying figures, where like reference numerals refer to identical or functionally similar elements throughout the separate views, together with the detailed description below, are incorporated in and form part of the specification, and serve to further illustrate embodiments of concepts that include the claimed invention, and explain various principles and advantages of those embodiments.

FIG. **1** is a block diagram of a wireless power transfer system.

FIGS. **2**A and **2**B are diagrams of a wireless power transfer device of the wireless power transfer system of FIG. **1**.

FIG. **3** is flowchart illustrating a method of transferring wireless power using the wireless power transfer device of FIGS. **2**A and **2**B.

FIG. **4** is a diagram of a second wireless power transfer device.

FIG. **5** is a diagram of a third wireless power transfer device.

FIG. **6** is a diagram of a fourth wireless power transfer device.

FIG. **7** is a diagram of a fifth wireless power transfer device.

Skilled artisans will appreciate that elements in the figures are illustrated for simplicity and clarity and have not necessarily been drawn to scale. For example, the dimensions of some of the elements in the figures may be exaggerated relative to other elements to help to improve understanding of embodiments of the present invention.

The apparatus and method components have been represented where appropriate by conventional symbols in the drawings, showing only those specific details that are pertinent to understanding the embodiments of the present invention so as not to obscure the disclosure with details that will be readily apparent to those of ordinary skill in the art having the benefit of the description herein.

DETAILED DESCRIPTION OF THE INVENTION

One embodiment provides a wireless power transfer device that includes a first power amplifier configured to generate a first drive signal, and a second power amplifier configured to generate a second drive signal. In one particular instance, the wireless power transfer device also includes a first transmitter coil electrically coupled to the first power amplifier, a second transmitter coil electrically coupled to the second power amplifier, and a repeater coil magnetically coupled to the first transmitter coil and the second transmitter coil. The first transmitter coil is configured to generate a

first magnetic field having a first magnitude in response to receiving the first drive signal. The second transmitter coil is configured to generate a second magnetic field having a second magnitude in response to receiving the second drive signal. The repeater coil is configured to generate a third magnetic field having a third magnitude. The third magnitude is greater than the first magnitude and is also greater than the second magnitude. The repeater coil is also configured to magnetically transfer power to an external device.

Another embodiment provides a method of wirelessly transferring power with a wireless power transfer device. The wireless power transfer device includes a first transmitter coil, a second transmitter coil, and a repeater coil. In one instance, the method includes electrically coupling a first power amplifier to the first transmitter coil, generating a first drive signal with the first power amplifier, and generating, with the first transmitter coil, a first magnetic field having a first magnitude in response to receiving the first drive signal. The method also includes electrically coupling a second power amplifier to the second transmitter coil, generating a second drive signal with the second power amplifier, and generating, with the second transmitter coil, a second magnetic field having a second magnitude in response to receiving the second drive signal. The method further includes magnetically coupling the first transmitter coil and the second transmitter coil with the repeater coil, and generating, with the repeater coil, a third magnetic field having a third magnitude. The third magnitude is greater than the first magnitude and is also greater than the second magnitude.

Another embodiment provides a wireless power transfer system. In one instance, the system includes a wireless power transfer device that has a wireless power transfer array. The wireless power transfer array includes a first plurality of power amplifiers configured to generate a first plurality of drive signals, a first plurality of transmitter coils configured to generate a first plurality of magnetic fields, each transmitter coil electrically coupled to one of the first plurality of power amplifiers, each magnetic field being phase aligned to be additively combined with the other magnetic fields from the first plurality of magnetic fields, and a first repeater coil. The first repeater coil is magnetically coupled to the first plurality of transmitter coils and configured to additively combine the first plurality of magnetic fields. The wireless power transfer device is configured to transfer power to a predetermined power transfer area and within a predetermined power transfer distance. The system also includes an external device including a receiver coil magnetically coupled to the first repeater coil and configured to receive wireless power from the wireless power transfer device when the receiver coil is positioned within the predetermined power transfer area and the predetermined power transfer distance.

FIG. **1** illustrates a wireless power transfer system **100** including a wireless power transfer device **105** and an external device **110**. In the example illustrated, the external device **110** includes, among other things, a receiver coil **113**. The receiver coil **113** magnetically couples to the wireless power transfer device **105** to receive electrical power from the wireless power transfer device **105**. The external device **110** may be, for example, a battery. The battery may be located in a smart telephone, a tablet computer, or other electrical device. For the sake of simplicity, the particular components of the external device **110** are not shown, but are understood by one of skill in the art.

In the embodiment illustrated, the wireless power transfer device **105** transfers power wirelessly to the external device **110** through magnetic resonance. In magnetic-resonance power transfer, a transmitter coil receives power from, for example, a power amplifier, and generates a magnetic field. A receiver coil is placed in close proximity to the transmitter coil, and magnetically couples to the transmitter coil to receive electrical power from the transmitter coil. In magnetic-resonance power transfer, the distance between the transmitter coil and the receiver coil (i.e., the power transfer distance) is typically within a few centimeters (cm). Performing efficient power transfer at greater distances when using magnetic-resonance power transfer is challenging because the strength of the magnetic field generated by the transmitter coil decreases rapidly as the power transfer distance increases.

As shown in FIG. **1**, the wireless power transfer device **105** includes a first power amplifier **115**, a first transmitter coil **120**, a second power amplifier **125**, a second transmitter coil **130**, a repeater coil **135**, an internal reference clock **140**, and an electronic processor **145**. The wireless power transfer device **105** may also include a housing (not shown) that supports the first power amplifier **115**, the first transmitter coil **120**, the second power amplifier **125**, the second transmitter coil **130**, the repeater coil **135**, the internal reference clock **140**, and the electronic processor **145**.

As shown in FIG. **2**A, the first transmitter coil **120** includes a first looped wire (e.g., a copper wire and the like) having a first positive terminal **150** and a first negative terminal **155**. The first transmitter coil **120** is electrically coupled to the first power amplifier **115**. The first power amplifier **115** generates a first drive signal having a first magnitude and a first phase that is provided to the first transmitter coil **120**. The first transmitter coil **120** generates a first magnetic field in response to receiving the first drive signal from the first power amplifier **115**. The second transmitter coil **130** also includes a second looped wire (e.g., a copper wire and the like) having a second positive terminal **160** and a second negative terminal **165**. The second transmitter coil **130** is electrically coupled to the second power amplifier **125**. The second power amplifier **125** generates a second drive signal having a second magnitude and a second phase that is provided to the second transmitter coil **130**. The second transmitter coil **130** generates a second magnetic field in response to receiving the second drive signal from the second power amplifier **125**.

The first power amplifier **115** and the second power amplifier **125** are electrically coupled to a first clock source **170** and a second clock source **175**, respectively. In the illustrated embodiment, the first clock source **170** and the second clock source **175** operate within the frequency range of 6.765 Megahertz (MHz) to 6.795 Megahertz. In some embodiments, the first clock source **170** and the second clock source **175** may operate in different frequency ranges. The first clock source **170** and the second clock source **175** are electrically coupled to the internal reference clock **140** such that the first drive signal and the second drive signal are synchronized according to the internal reference clock **140**. In the illustrated embodiment, the internal reference clock **140** operates at a frequency of 34.56 Megahertz. In some embodiments, the internal reference clock **140** may operate at a different frequency. Additionally, the first drive signal and the second drive signal are phase aligned such that the second magnetic field has a phase difference with respect to the first magnetic field that maximizes a combination of the first magnetic field and the second magnetic field. In one embodiment, the first power amplifier **115** generates the first drive signal at a reference phase angle, while the second power amplifier **125** generates the second drive signal at a phase angle of 330 degrees. In some embodiments, the specific phase angle between the first drive signal and the second drive signal is different based on, for example, the placement of the first transmitter coil **120** and the second transmitter coil **130** with respect to each other and to the repeater coil **135**.

The repeater coil **135** is magnetically coupled to the first transmitter coil **120** and to the second transmitter coil **130**. Notably, the repeater coil **135** is not electrically connected to the first power amplifier **115** or to the second power amplifier **125**. The repeater coil **135** includes a high quality ("Q") factor to ensure a strong magnetic coupling between the first transmitter coil **120** and the repeater coil **135**, and between the second transmitter coil **130** and the repeater coil **135**. The quality factor is a dimensionless parameter that indicates the energy losses within a resonant element (e.g., the repeater coil **135**). The higher the quality factor, the lower the rate of energy loss. Because of its high quality factor, the repeater coil **135** additively combines the first magnetic field with the second magnetic field and efficiently (e.g., with minimal energy loss) generates a third magnetic field. The second magnetic field has a phase difference of 330 degrees with respect to the first magnetic field due to the phase difference between the first drive signal and the second drive signal. In some embodiments, the phase difference between the first magnetic field and the second magnetic field based on, for example, the placement of the first transmitter coil **120** and the second transmitter coil **130** with respect to each other and to the repeater coil **135**. The repeater coil **135** generates, in response to combining the first magnetic field and the second magnetic field, the third magnetic field having a third magnitude. The phase difference between the first magnetic field and the second magnetic field allows the first magnetic field and the second magnetic field to be additively combined, which maximizes the third magnitude of the third magnetic field. Therefore, the third magnitude of the third magnetic field is, in an ideal configuration, equal to a sum of the first magnitude of the first magnetic field and the second magnitude of the second magnetic field. Because, however, the first transmitter coil **120**, the second transmitter coil **130**, the first power amplifier **115**, the second power amplifier **125**, the repeater coil **135** and the like are not ideal components, the third magnitude of the third magnetic field may be slightly less than the exact sum of the first magnitude of the first magnetic field and the second magnitude of the second magnetic field. When the receiver coil **113** is within a power transfer area and within a power transfer distance, the receiver coil **113** is magnetically coupled to the repeater coil **135**. As a consequence, electrical power is transferred from the wireless power transfer device **105** to the receiver coil **113**.

In one particular embodiment, as shown in FIG. **2**A, the first transmitter coil **120** has a first length **180** of eighteen (18) centimeters (cm) and a first width **185** of twelve (12) centimeters. It should be understood; however, that these dimensions (as well as other dimensions provided herein) are examples and that different dimensions could be used. As shown in FIG. **2**B, the first transmitter coil **120** also includes a first portion **190** located at a first longitudinal end **195** of the first transmitter coil **120** along the first length **180**. In the illustrated embodiment, the second transmitter coil **130** has a similar construction as the first transmitter coil **120**. For example, as shown in FIG. **2**A, the second transmitter coil **130** has a second length **200** of eighteen centimeters and a second width **205** of twelve centimeters. Again, these dimension are examples and different dimensions can alternatively be used. As shown in FIG. **2**B, the second transmitter coil **130** also includes a second portion **210** located at a second longitudinal end **215** of the second transmitter coil **130** along the second length **200**. In other embodiments, the first portion **190** of the first transmitter coil **120** is aligned along the first width **185** and the second portion **210** the second transmitter coil **130** is aligned along the second width **205**.

Referring back to FIG. **2**A, the repeater coil **135** has a third length **220** of sixteen (16) centimeters and a third width **225** of ten (10) centimeters. The repeater coil **135** has a first plurality of edges **230***a* through **230***d* defining a perimeter **235** of the repeater coil **135**. In the illustrated embodiment, the repeater coil **135** has a rectangular shape. In other embodiments, however, the repeater coil **135** may have a different shape (e.g., triangular, hexagonal, and the like) and/or may have different dimensions to those described above. As shown in FIG. **2**B, the repeater coil **135** has a third portion **240** located at one of the edges **230***a* along the third width **225**, and a fourth portion **245** located at another one of the edges **230***c* along the third width **225**.

As shown in FIG. **2**B, the first transmitter coil **120** is positioned such that the third portion **240** of the repeater coil **135** overlaps the first portion **190** of the first transmitter coil **120** in a first overlap region **250** (i.e., the third portion **240** and the first portion **190** overlap in the first overlap region **250**). The second transmitter coil **130** is positioned such that the fourth portion **245** of the repeater coil **135** overlaps the second portion **210** of the second transmitter coil **130** in a second overlap region **255** (i.e., the second portion **210** and the fourth portion **245** overlap in the second overlap region **255**). As shown in FIG. **2**B, the size of the first overlap region **250** and the second overlap region **255** is smaller than the size of the first transmitter coil **120**, smaller than the size of the second transmitter coil **130**, and smaller than the size of the repeater coil **135**. In other words, the first transmitter coil **120**, the second transmitter coil **130**, and the repeater coil **135** are only partially overlapped. The sizes (e.g., area and dimensions) of the first overlap region **250** and of the second overlap region **255** are not arbitrary, and are determined based on, for example, one or more of the geometry of the first transmitter coil **120**; the geometry of the second transmitter coil **130**; the geometry of the repeater coil **135**; the number of turns of the first transmitter coil **120**, the second transmitter coil **130**, and/or the repeater coil **135**; the width of turns of the first transmitter coil **120**, the second transmitter coil **130**, and/or the repeater coil **135**; and the spacing between the turns of the first transmitter coil **120**, the second transmitter coil **130**, and/or the repeater coil **135**, among other things.

As shown in FIG. **2**B, the wireless power transfer device **105** also includes a first flux concentrator **260** that concentrates a first magnetic flux between the first transmitter coil **120** and the repeater coil **135**. In other words, the first flux concentrator **260** maximizes the magnetic flux coupling between the first transmitter coil **120** and the repeater coil **135** while minimizing magnetic losses in the coupling. In the illustrated embodiment, the first flux concentrator **260** is aligned with the first overlap region **250** and is positioned between the first transmitter coil **120** and the repeater coil **135**. In this position, due to its material properties, the first flux concentrator **260** can improve the return loss when the first transmitter coil **120** and the repeater coil **135** are magnetically coupled. The wireless power transfer device **105** also includes a second flux concentrator **265** that concentrates a second magnetic flux between the second transmitter coil **130** and the repeater coil **135**. In other words, the second flux concentrator **265** maximizes the magnetic flux coupling between the second transmitter coil **130** and the repeater coil **135** while minimizing magnetic losses in the coupling. In the illustrated embodiment, the second flux concentrator **265** is aligned with the second overlap region **255** and is positioned between the second transmitter coil **130** and the repeater coil **135**. In this position, due to its material properties, the second flux concentrator **265** can improve the return loss when the second transmitter coil **130** and the repeater coil **135** are magnetically coupled. In the illustrated embodiments, the first flux concentrator **260** and the second flux concentrator **265** include a ferrite layer. The first flux concentrator **260** and the second flux concentrator **265** have a high permeability (e.g., 120) and low-loss factor (e.g., 0.017). In the illustrated embodiment of FIG. **2**B the first flux concentrator **260** and the second flux concentrator **265** each have a height **270** of 0.3 mm (millimeters). In some embodiments, the first flux concentrator **260** and/or the second flux concentrator **265** each may have a different height.

In the embodiment illustrated in FIG. **2**B, the wireless power transfer device **105** includes a first insulation layer **275***a*, a second insulation layer **275***b*, a third insulation layer **275***c*, and a fourth insulation layer **275***d* that separate the first transmitter coil **120** from the repeater coil **135**, and the second transmitter coil **130** from the repeater coil **135**. The first insulation layer **275***a*, the second insulation layer **275***b*, the third insulation layer **275***c*, and the fourth insulation layer **275***d* include a passive material and are used to keep the first transmitter coil **120** and the second transmitter coil **130** at an appropriate distance **280** apart from the repeater coil **135**, keep the first flux concentrator **260** at an appropriate distance from the repeater coil **135** and from the first transmitter coil **120**, and keep the second flux concentrator **265** at an appropriate distance from the repeater coil **135** and from the second transmitter coil **130**. In one exemplary embodiment, each insulation layer **275***a* through **275***d* has a height **285** of six (6) millimeters. In some embodiments, each insulation layer **275***a* through **275***d* may have a different height. As shown in FIG. **2**B, the first flux concentrator **260** is positioned between the first insulation layer **275***a* and the second insulation layer **275***b* while the second flux concentrator **265** is positioned between the third insulation layer **275***c* and the fourth insulation layer **275***d*.

The distance **280** between the first transmitter coil **120** and the repeater coil **135**, and the second transmitter coil **130** and the repeater coil **135** is not arbitrary, and is determined based on, for example, one or more of the geometry of the first transmitter coil **120**, the second transmitter coil **130**, and/or the repeater coil **135**, the number of turns in the first transmitter coil **120**, the second transmitter coil **130**, and/or the repeater coil **135**, and the like. In the illustrated embodiment, the distance **280** between the first transmitter coil **120** and the repeater coil **135**, and between the second transmitter coil **130** and the repeater coil **135** is fifteen (15) millimeters. Since the components used (i.e., the insulation layers **275***a* through **275***d*, the first flux concentrator **260**, and the second flux concentrator **265**) are not ideal, the distance **280** between the first transmitter coil **120** and the repeater coil **135**, and between the second transmitter coil **130** and the repeater coil **135** may be slightly less or slightly more than fifteen millimeters. In some embodiments, the distance between the first transmitter coil **120** and the repeater coil **135**, and between the second transmitter coil **130** and repeater coil **135** may be different than the fifteen millimeters. Additionally, since the first transmitter coil **120**, the second transmitter coil **130**, and the repeater coil **135** are generally flat (e.g., their respective heights are negligible), the assembly (i.e., the first transmitter coil **120**, the second transmitter coil **130**, the first flux concentrator **260**, the second flux concentrator **265**, the insulation layers **275***a* through **275***d*, and the repeater coil **135**) also have a height of fifteen millimeters, with some variation since the components used are not ideal.

FIG. **3** illustrates an exemplary method **300** of transferring wireless power. As shown in FIG. **3**, the method **300** includes overlapping the first transmitter coil **120** with the repeater coil **135** (block **303**), which includes overlapping the first portion **190** of the first transmitter coil **120** with the third portion **240** of the repeater coil **135** in a first overlap region **250**. The method **300** also includes overlapping the second transmitter coil **130** with the repeater coil **135** (block **304**) by overlapping the second portion **210** of the second transmitter coil **130** with the fourth portion **245** of the repeater coil **135** in a second overlap region **255**. The method **300** further includes aligning the first flux concentrator **260** with the first overlap region **250** (block **305**), and aligning the second flux concentrator **265** with the second overlap region **255** (block **307**). Additionally, the method **300** includes electrically coupling the first power amplifier **115** to the first transmitter coil **120** (block **309**), and electrically coupling the second power amplifier **125** to the second transmitter coil **130** (block **311**). Then, the method **300** includes generating the first drive signal (block **315**). As discussed above, the first drive signal is generated by the first power amplifier **115**. The method **300** also includes generating the second drive signal (block **320**). As also discussed above, the second power amplifier **125** generates the second drive signal. As discussed above, the first power amplifier **115** and the second power amplifier **125** synchronize the first drive signal and the second drive signal according to the internal reference clock **140**. Additionally, the second drive signal has a phase difference of 330 degrees with respect to the first drive signal. The method **300** also includes generating a first magnetic field (block **325**) and generating a second magnetic field (block **330**). The first transmitter coil **120** generates the first magnetic field in response to receiving the first drive signal, and the second transmitter coil **130** generates the second magnetic field in response to receiving the second drive signal. The method **300** further includes magnetically coupling the repeater coil **135** with the first transmitter coil **120** and the second transmitter coil **130** (block **335**). The repeater coil **135** magnetically couples to the first transmitter coil **120** and the second transmitter coil **130** in response to the generation of the first magnetic field and the second magnetic field.

Because the repeater coil **135** is magnetically coupled to the first transmitter coil **120** and the second transmitter coil **130**, which are independently powered by a first power amplifier **115** and a second power amplifier **125**, respectively, the repeater coil **135** can additively combine the magnitude of the first magnetic field and the magnitude of the second magnetic field. Therefore, the method **300** also includes generating a third magnetic field having a magnitude equal to a sum of a first magnitude of the first magnetic field and a second magnitude of the second magnetic field (block **340**). Because, however, the first transmitter coil **120**, the second transmitter coil **130**, the first power amplifier **115**, the second power amplifier **125**, the repeater coil **135** and the like are not ideal components, the third magnitude of the third magnetic field may be slightly less than the exact sum of the first magnitude of the first magnetic field and the second magnitude of the second magnetic field. The third magnetic field is generated by the repeater coil **135** as a combination of the first magnetic field and the second magnetic field. The phase difference between the first magnetic field and the second magnetic field, as well as the synchronization of the first power amplifier **115** and the second power amplifier **125** with respect to the internal reference clock **140** allows the repeater coil **135** to efficiently combine the first magnetic field and the second magnetic field.

Due to the increased strength of the third magnetic field in comparison with the first magnetic field and/or the second magnetic field, the power transfer area associated with the wireless power transfer device **105** is increased in comparison to using just the first transmitter coil **120** or the second transmitter coil **130**. Additionally, the additive combination of the first magnetic field and the second magnetic field also increases the power transfer distance (i.e., the distance between the receiver coil **113** and the wireless power transfer device **105** at which the receiver coil **113** still receives at least 500 milliamps of power from the wireless power transfer device **105**) in comparison to using the first transmitter coil **120** and the second transmitter coil **130** without the repeater coil **135**. In one exemplary embodiment, the wireless power transfer device **105** provides a current of 640 milliamps (e.g., the current may be slightly lower or higher than 640 milliamps due to the use of non-ideal components) when the receiver coil **113** is 8.5 centimeters apart (e.g., there may be a small difference in the distance between the receiver coil **113** and the wireless power transfer device **105** due to the different non-ideal components used). In the illustrated embodiment, a ratio of power transfer distance to the distance between the first transmitter coil **120** or the second transmitter coil **130** and the repeater coil **135** (e.g., 15 millimeters) is 5.7, when rounded to the nearest tenth. This ratio provides an indication of the compactness of the wireless power transfer device **105** with respect to the power transfer distance associated with the wireless power transfer device **105**.

There are a number of other ways in which the power transfer distance may be increased. One is to increase the output power from the power amplifier to the transmitter coil. Another is to increase the size of the transmitter coil. Yet another possible solution is to use a transmitter and repeater arrangement to increase the power transfer distance. All of these mechanisms, however, suffer from one or more deficiencies. Designing and building power amplifiers with high output power can be difficult. Increasing the size of the transmitter coil also increases the size of the wireless power transfer device as a whole. Lastly, transmitter and repeater arrangements are often cumbersome.

FIG. **4** illustrates a second wireless power transfer device **400**. As shown in FIG. **4**, the second wireless power transfer device **400** includes three transmitter coils instead of the two transmitter coils used in the first wireless power transfer device **105**. Using three transmitter coils magnetically coupled to a repeater coil allows the repeater coil to additively combine three different magnetic fields, thereby increasing the power transfer distance in comparison to the wireless power transfer device **105** that only additively combines two different magnetic fields. In the example illustrated, the second wireless power transfer device **400** adds a third transmitter coil **410** to the wireless power transfer device **105** described with respect to FIGS. **1** through **3**. Accordingly, the second wireless power transfer device **400** includes the first power amplifier **115**, the first transmitter coil **120**, the second power amplifier **125**, the second transmitter coil **130**, a third power amplifier **405**, a third transmitter coil **410**, and the repeater coil **135**. The second wireless power transfer device **400** may also include other components similar to the first power transfer device

105 that are not shown in FIG. 4. The specific description of these components may be omitted, but it is understood that their function is similar to that described above with respect to the first wireless power transfer device 105.

The third transmitter coil 410 is electrically coupled to the third power amplifier 405. The third power amplifier 405 generates a third drive signal having a fourth magnitude and a third phase. The third drive signal is provided to the third transmitter coil 410. The third transmitter coil 410 generates a fourth magnetic field in response to receiving the third drive signal from the third power amplifier 405. The third power amplifier 405 is electrically coupled to a third clock source 415 that, in the illustrated embodiment, operates within the frequency range of 6.765 Megahertz (MHz) to 6.795 Megahertz. In some embodiments, the third clock source 415 may operate in different frequency ranges. The third clock source 415 is also electrically coupled to the internal reference clock 140 such that the first drive signal, the second drive signal, and the third drive signal are synchronized according to the internal reference clock 140. Additionally, the first drive signal, the second drive signal, and the third drive signal as generated in the second wireless power transfer device 400, are phase aligned such that the second magnetic field and the fourth magnetic field each has a phase difference with respect to the first magnetic field that maximizes a combination of the first magnetic field, the second magnetic field, and the fourth magnetic field. In the illustrated embodiment, the first power amplifier 115 generates the first drive signal at a reference phase angle, the second power amplifier 125 generates the second dive signal at a phase angle of 290 degrees (e.g., the phase difference may be slightly more or less due to, for example, variations in non-ideal components), and the third power amplifier 405 generates the third drive signal at a phase angle of 210 degrees (e.g., the phase difference may be slightly more or less due to, for example, variations in non-ideal components).

In the second wireless power transfer device 400, the repeater coil 135 is magnetically coupled to the first transmitter coil 120, the second transmitter coil 130, and the third transmitter coil 410. The repeater coil 135 additively combines the first magnetic field, the second magnetic field, and the fourth magnetic field. The repeater coil 135 generates, in response to combining the first magnetic field, the second magnetic field, and the fourth magnetic field, the third magnetic field with the third magnitude equal to a sum of the first magnitude of the first magnetic field, the second magnitude of the second magnetic field, and the fourth magnitude of the fourth magnetic field. Because, however, the first transmitter coil 120, the second transmitter coil 130, the third transmitter coil 410, the first power amplifier 115, the second power amplifier 125, the third power amplifier 405, the repeater coil 135 and the like are not ideal components, the third magnitude of the third magnetic field may be slightly less than the exact sum of the first magnitude of the first magnetic field, the second magnitude of the second magnetic field, and the fourth magnitude of the fourth magnetic field. The phase difference between the first magnetic field, the second magnetic field, and the fourth magnetic field maximizes the third magnitude of the third magnetic field.

The third transmitter coil 410 has a fourth length 420 of eighteen centimeters and a fourth width 425 of twelve centimeters. As stated before, it should be understood that these dimensions are only examples and that other embodiments may have different dimensions. The third transmitter coil 410 includes a fifth portion 430 located at a first longitudinal end 435 of the third transmitter coil 410 along the fourth width 425. The repeater coil 135 also includes a sixth portion 440 as shown in FIG. 4 located at one of the edges 230*b* (FIG. 2A) along the third length 220 (FIG. 2A).

As shown in FIG. 4, the third transmitter coil 410 is positioned such that the sixth portion 440 of the repeater coil 135 overlaps the fifth portion 430 of the third transmitter coil 410 in a third overlap region 445. As shown in FIG. 4, the size of the third overlap region 445 is also smaller than the size of the third transmitter coil 410 and smaller than the size of the repeater coil 135. In other words, the third transmitter coil 410 and the repeater coil 135 are only partially overlapped. As discussed above with respect to the first overlap region 250, the size of the third overlap region 445 is not arbitrary and is determined based on, for example, one or more of the geometry of the third transmitter coil 410, the geometry of the repeater coil 135, the number of turns in the third transmitter coil 410 or the repeater coil 135, and the like.

The rest of the components of the second wireless power transfer device 400 operate similar to those included in the first power transfer device 105. For example, in the illustrated embodiment, the second wireless power transfer device 400 also includes a third flux concentrator (not shown) that concentrates the fourth magnetic flux between the third transmitter coil 410 and the repeater coil 135. In other words, the third flux concentrator (not shown) maximizes the magnetic flux coupling between the third transmitter coil 410 and the repeater coil 135 while minimizing magnetic losses in the coupling. The third flux concentrator is also aligned with the third overlap region 445 and is positioned between the third transmitter coil 410 and the repeater coil 135. In this position, the third flux concentrator, which in the second wireless power transfer device 400 includes a ferrite material, can improve the return loss when the third transmitter coil 410 and the repeater coil 135 are magnetically coupled due to its material properties. The third flux concentrator, also due to its material properties, has a high permeability (e.g., 120) and low-loss factor (e.g., 0.017).

Additionally, the second wireless power transfer device 400 also includes fifth insulation layer and a sixth insulation layer (not shown) that maintains the third transmitter coil 410 and the repeater coil 135 at an appropriate distance apart. In the illustrated embodiment, the fifth insulation layer and the sixth insulation layer each have a height of 6 millimeters. In some embodiments, the fifth insulation layer and the sixth insulation layer may each have a different height. Therefore, in the illustrated embodiment, the distance between the first transmitter coil 120, the second transmitter coil 130, or the third transmitter coil 410 and the repeater coil 135 is fifteen millimeters. In some embodiments, the distance between the first transmitter coil 120, the second transmitter coil 130, or the third transmitter coil 410 and the repeater coil 135 may be different than the fifteen millimeters specified above.

The repeater coil 135 is magnetically coupled to the first transmitter coil 120, the second transmitter coil 130, and the third transmitter coil 410, which are each independently powered by the first power amplifier 115, the second power amplifier 125, and the third power amplifier 405, respectively. As a consequence, the repeater coil 135 can additively combine the magnitude of the first magnetic field, the magnitude of the second magnetic field, and the magnitude of the fourth magnetic field. The repeater coil 135 then generates the third magnetic field having a magnitude equal to a sum of a magnitude of the first magnetic field, a magnitude of the second magnetic field, and a magnitude of the fourth magnetic field. Because, however, the first transmitter coil **120**, the second transmitter coil **130**, the third transmitter coil **410**, the first power amplifier **115**, the second power amplifier **125**, the third power amplifier **405**, the repeater coil **135** and the like are not ideal components, the third magnitude of the third magnetic field may be slightly less than the exact sum of the first magnitude of the first magnetic field, the second magnitude of the second magnetic field, and the fourth magnitude of the fourth magnetic field. The phase difference between the first magnetic field, the second magnetic field, and the fourth magnetic field, as well as the synchronization of the first power amplifier **115**, the second power amplifier **125**, and the third power amplifier **405** with respect to the internal reference clock **140** allows the repeater coil **135** to efficiently combine the first magnetic field, the second magnetic field, the fourth magnetic field.

Due to the increased strength of the third magnetic field in comparison with the first magnetic field and/or the second magnetic field, the power transfer area associated with the second wireless power transfer device **400** is increased in comparison to using just the first transmitter coil **120** or the second transmitter coil **130**. Additionally, the additive combination of the first magnetic field, the second magnetic field, and the fourth magnetic field also increases the power transfer distance in comparison to using the first transmitter coil **120**, the second transmitter coil **130**, and the third transmitter coil **410** without the repeater coil **135**. In one exemplary embodiment, the second wireless power transfer device **400** provides a current of 950 milliamps (e.g., the current may be slightly lower or higher than 950 milliamps due to the use of non-ideal components) when the receiver coil **113** is 8.5 centimeters apart (e.g., there may be a small difference in the distance between the receiver coil **113** and the second wireless power transfer device **400** due to the different non-ideal components used), and the same exemplary embodiment or a different embodiment provides a current of 100 milliamps (e.g., the current may be slightly lower or higher than the 100 milliamps due to the use of non-ideal components) when the receiver coil **113** is 16.5 centimeters apart (e.g., there may be a small difference in the distance between the receiver coil **113** and the second wireless power transfer device **400** due to the different non-ideal components used). In the illustrated embodiment, a ratio of the power transfer distance to the distance between the first transmitter coil **120**, the second transmitter coil **130**, or the third transmitter coil **410**, and the repeater coil **135** is 11, when rounded. This ratio provides an indication of the compactness of the second wireless power transfer device **400** with respect to the power transfer distance associated with the wireless power transfer device **400**.

As demonstrated with the description of the second wireless device **400**, the wireless power transfer device **105** can be expanded such that a plurality of transmitter coils, each individually powered by a power amplifier, are magnetically coupled to repeater coil. The more transmitter coils that are magnetically coupled to the repeater coil, the stronger (i.e., greater magnitude) the magnetic field generated by the repeater coil is. FIG. **5** illustrates a diagram of a third wireless power transfer device **500**. The third wireless power transfer device **500** includes a repeater coil **505** that is magnetically coupled to a plurality of transmitter coils **510***a* through **510***d*, each of which is individually powered by one of a plurality of power amplifiers **515***a* through **515**-*d*. To have the repeater coil **505** additively combine the magnetic fields generated by the plurality of magnetic fields from the plurality of transmitter coils **510***a* through **510***d*, the drive signals generated by each of the plurality of power amplifiers **515***a* through **515***d* are synchronized with an internal clock source and are phase aligned to maximize the superposition of the plurality of magnetic fields. Therefore, the third wireless power transfer device **500** is associated with a greater power transfer distance than the first wireless power transfer device **105** and the second wireless power transfer device **400**.

FIG. **6** illustrates a fourth wireless power transfer device **600**. The fourth wireless power transfer device **600** includes a repeater coil **605** that is hexagonally shaped. Due to its hexagonal shape, the repeater coil **605** may magnetically couple to a maximum of six different transmitter coils **610***a* through **610***f*, each of which is individually powered by one of a plurality of power amplifiers **615***a* through **615***f* To have the repeater coil **605** additively combine the magnetic fields generated by the plurality of transmitter coils **610***a* through **610***f*, the drive signals generated by each of the plurality of power amplifiers **615***a* through **615***f* are synchronized with an internal clock source and are phase aligned to maximize the additive superposition of the plurality of the magnetic fields. Therefore, the fourth wireless power transfer device **600** is associated with a greater transfer distance than the first wireless power transfer device **105**, the second wireless power transfer device **400**, and the third wireless power transfer device **500**. Additionally, the distance between the repeater coil **605** and each of the transmitter coils **610***a* through **610***f* remains the same (for example, fifteen millimeters), which provides a greater ratio of power transfer distance to distance between the repeater coil **605** and each of the transmitter coils **610***a-f*.

FIG. **7** illustrates a modular fifth wireless power transfer device **700**. The fifth wireless power transfer device **700** is an expandable power transfer device **700** because it includes a first wireless power transfer array **705**, a second wireless power transfer array **710**, and a third wireless power transfer array **713**. The first wireless power transfer array **705** includes a hexagonal repeater coil **715** (similar to the hexagonal repeater coil **605** shown in FIG. **6**) magnetically coupled to a first plurality of transmitter coils **720***a* through **720***f*. The first repeater coil **715** includes a first plurality of edges **716***a* through **716***f*. The first repeater coil **715** is magnetically coupled to the first plurality of transmitter coils **720***a* through **720***f* at the first plurality of edges **716***a* through **716***f*. Each of the first plurality of transmitter coils **720***a* through **720***f* are electrically coupled and powered by a first plurality of power amplifiers. The first plurality of transmitter coils **720** *a* through **720***f* generate a first plurality of magnetic fields that are phase aligned to be additively combined with the rest of the first plurality of magnetic fields (i.e., with each other). The hexagonal repeater coil **715** is magnetically coupled to each of the first plurality of transmitter coils **720***a* through **720***f* and additively combines the first plurality of magnetic fields and generates a first magnetic field with a magnitude equal to a sum of the magnitudes of the first plurality of magnetic fields. Because, however, the first plurality of transmitter coils **720***a* through **720***f* and the like are not ideal components, the magnitude of the first magnetic field generated by the hexagonal repeater coil **715** may be slightly less than the exact sum of the magnitudes of the first magnetic fields generated by the first plurality of transmitter coils **720***a* through **720***f*.

The second wireless power transfer array **710** includes a second hexagonal repeater coil **730** magnetically coupled to a second plurality of transmitter coils **735***a* through **735***e*. The second repeater coil **730** includes a second plurality of edges **737***a* through **737***f*. The second hexagonal repeater coil **730** is magnetically coupled to the second plurality of transmitter coils **735***a* through **735***e*, and to one of the first plurality of transmitter coils **720***a*. The second plurality of transmitter coils **735***a* through **735***e* generate a second plurality of magnetic fields that are phase aligned to be additively combined with each other. The second hexagonal repeater coil **730** additively combines the second plurality of magnetic fields and one of the first plurality of magnetic fields to generate a second magnetic field with a magnitude equal to a sum of the magnitudes of the second plurality of magnetic fields and one of the first plurality of magnetic fields (e.g., magnetic field generated by transmitter coil **720***a* of the first plurality of transmitter coils **720***a* through **720***f*). Because, however, the components used are not ideal components, the magnitude of the second magnetic field generated by the second hexagonal repeater coil **730** may be slightly less than the exact sum of the magnitudes of the second plurality of magnetic fields and one of the first plurality of magnetic fields.

As shown in FIG. **7**, the first repeater coil **715** of the first wireless power transfer array **705** has every edge of the first plurality of edges **716***a* through **716***f* magnetically coupled to one of the first plurality of transmitter coils **720***a* through **720***f* The second repeater coil **730** also has every edge of the second plurality of edges **737***a* through **737***f* magnetically coupled to one of the second plurality of transmitter coils **735***a* through **735***f*. Therefore, both the first wireless power transfer array **705** and the second wireless power transfer array **710** have a maximum number of transmitter coils **720***a* through **720***f* and **735***a* through **735***e* magnetically coupled to the first repeater coil **715** and to the second repeater coil **730**. The third wireless power transfer array **713** includes a third repeater coil **750** and one transmitter coil **755**. The third repeater coil **750** includes a third plurality of edges **757***a* through **757***f* defining a third perimeter of the third repeater coil **750**. The third repeater coil **750** is magnetically coupled to the one transmitter coil **755**, to one of the first plurality of transmitter coils **720***f*, and to one of the second plurality of transmitter coils **735***a*. The third repeater coil **750**, however, still has a plurality of edges **757***b* through **757***d* that remain magnetically uncoupled to any transmitter coils. These plurality of edges **757***b* through **757***d* therefore provide an expandable capability to the fifth wireless power transfer device **700**. In other words, while these plurality of edges **757***b* through **757***d* are, in the illustrated embodiment, uncoupled to any transmitter coils, transmitter coils and/or an additional wireless power transfer array may be added to any one of the uncoupled plurality of edges **757***b* through **757***d*.

Each wireless power transfer array **705**, **710**, **713** may be magnetically coupled and decoupled from each other to produce different sizes of wireless power transfer devices **700** being associated with different power transfer areas and power transfer distances. The power transfer area and the power transfer distance of a wireless power transfer device **700** may be expanded by adding and magnetically coupling an additional wireless power transfer array to an existing wireless power transfer array of the wireless power transfer device **700**. Therefore, by using modular wireless power transfer arrays, the power transfer area and/or the power transfer distance can be easily modified and adjusted for specific applications.

In the foregoing specification, specific embodiments have been described. However, one of ordinary skill in the art appreciates that various modifications and changes can be made without departing from the scope of the invention as set forth in the claims below. Accordingly, the specification and figures are to be regarded in an illustrative rather than a restrictive sense, and all such modifications are intended to be included within the scope of present teachings.

The benefits, advantages, solutions to problems, and any element(s) that may cause any benefit, advantage, or solution to occur or become more pronounced are not to be construed as a critical, required, or essential features or elements of any or all the claims. The invention is defined solely by the appended claims including any amendments made during the pendency of this application and all equivalents of those claims as issued.

Moreover in this document, relational terms such as first and second, top and bottom, and the like may be used solely to distinguish one entity or action from another entity or action without necessarily requiring or implying any actual such relationship or order between such entities or actions.

The terms "comprises," "comprising," "has", "having," "includes", "including," "contains", "containing" or any other variation thereof, are intended to cover a non-exclusive inclusion, such that a process, method, article, or apparatus that comprises, has, includes, contains a list of elements does not include only those elements but may include other elements not expressly listed or inherent to such process, method, article, or apparatus. An element proceeded by "comprises . . . a", "has . . . a", "includes . . . a", "contains . . . a" does not, without more constraints, preclude the existence of additional identical elements in the process, method, article, or apparatus that comprises, has, includes, contains the element. The terms "a" and "an" are defined as one or more unless explicitly stated otherwise herein.

The terms "substantially", "essentially", "approximately", "about" or any other version thereof, are defined as being close to as understood by one of ordinary skill in the art, and in one non-limiting embodiment the term is defined to be within 10%, in another embodiment within 5%, in another embodiment within 1% and in another embodiment within 0.5%. The term "coupled" as used herein is defined as connected, although not necessarily directly and not necessarily mechanically. A device or structure that is "configured" in a certain way is configured in at least that way, but may also be configured in ways that are not listed.

It will be appreciated that some embodiments may be comprised of one or more generic or specialized processors (or "processing devices") such as microprocessors, digital signal processors, customized processors and field programmable gate arrays (FPGAs) and unique stored program instructions (including both software and firmware) that control the one or more processors to implement, in conjunction with certain non-processor circuits, some, most, or all of the functions of the method and/or apparatus described herein. Alternatively, some or all functions could be implemented by a state machine that has no stored program instructions, or in one or more application specific integrated circuits (ASICs), in which each function or some combinations of certain of the functions are implemented as custom logic. Of course, a combination of the two approaches could be used.

Moreover, an embodiment can be implemented as a computer-readable storage medium having computer readable code stored thereon for programming a computer (e.g., comprising a processor) to perform a method as described and claimed herein. Examples of such computer-readable storage mediums include, but are not limited to, a hard disk, a CD-ROM, an optical storage device, a magnetic storage device, a ROM (Read Only Memory), a PROM (Programmable Read Only Memory), an EPROM (Erasable Programmable Read Only Memory), an EEPROM (Electrically Erasable Programmable Read Only Memory) and a Flash memory.

Further, it is expected that one of ordinary skill, notwithstanding possibly significant effort and many design choices motivated by, for example, available time, current technology, and economic considerations, when guided by the concepts and principles disclosed herein will be readily capable of generating such software instructions and programs and ICs with minimal experimentation.

The Abstract of the Disclosure is provided to allow the reader to quickly ascertain the nature of the technical disclosure. It is submitted with the understanding that it will not be used to interpret or limit the scope or meaning of the claims. In addition, in the foregoing Detailed Description, it can be seen that various features are grouped together in various embodiments for the purpose of streamlining the disclosure. This method of disclosure is not to be interpreted as reflecting an intention that the claimed embodiments require more features than are expressly recited in each claim. Rather, as the following claims reflect, inventive subject matter lies in less than all features of a single disclosed embodiment. Thus the following claims are hereby incorporated into the Detailed Description, with each claim standing on its own as a separately claimed subject matter.

What is claimed is:

1. A wireless power transfer device comprising:

a first power amplifier configured to generate a first drive signal;

a first transmitter coil electrically coupled to the first power amplifier, and configured to generate a first magnetic field having a first magnitude in response to receiving the first drive signal;

a second power amplifier configured to generate a second drive signal;

a second transmitter coil electrically coupled to the second power amplifier, and configured to generate a second magnetic field having a second magnitude in response to receiving the second drive signal; and

a repeater coil magnetically coupled to the first transmitter coil and the second transmitter coil, and configured to combine the first magnetic field and the second magnetic field to generate a third magnetic field having a third magnitude, wherein the third magnitude is greater than the first magnitude and is also greater than the second magnitude, the repeater coil configured to magnetically transfer power to an external device.

2. The wireless power transfer device of claim **1**, wherein the third magnitude is equal to or less than a sum of the first magnitude and the second magnitude.

3. The wireless power transfer device of claim **1**, wherein the second drive signal has a phase difference with respect to the first drive signal.

4. The wireless power transfer device of claim **3**, wherein the phase difference with respect to the first drive signal is three hundred (330) degrees.

5. The wireless power transfer device of claim **1**, wherein the first drive signal and the second drive signal are synchronized with an internal reference clock.

6. The wireless power transfer device of claim **1**, wherein:

the first transmitter coil includes a first portion;

the second transmitter coil includes a second portion; and

the repeater coil includes a third portion and a fourth portion, and wherein the repeater coil is positioned with respect to the first transmitter coil such that the first portion and the third portion overlap in a first overlap region, and wherein the repeater coil is positioned with respect to the second transmitter coil such that the second portion and the fourth portion overlap in a second overlap region.

7. The wireless power transfer device of claim **6**, further comprising a first flux concentrator aligned with the first overlap region and configured to concentrate a first magnetic flux of the first magnetic field.

8. The wireless power transfer device of claim **7**, further comprising a second flux concentrator aligned with the second overlap region, and configured to concentrate a second magnetic flux of the second magnetic field.

9. The wireless power transfer device of claim **8**, wherein a spacing of the first flux concentrator between the first transmitter coil and the repeater coil, and a spacing of the second flux concentrator between the second transmitter coil and the repeater coil are configured to provide a maximum power transfer.

10. The wireless power transfer device of claim **9**, wherein a ratio of a power transfer distance to a distance between the first transmitter coil and the second transmitter coil is at least 5.

11. The wireless power transfer device of claim **1**, further comprising a third power amplifier configured to generate a third drive signal, and a third transmitter coil electrically coupled to the third power amplifier and configured to generate a fourth magnetic field having a fourth magnitude in response to receiving the third drive signal, wherein the repeater coil is magnetically coupled to the first transmitter coil, the second transmitter coil, and the third transmitter coil, and wherein the third magnitude of the third magnetic field is equal to or less than a sum of the first magnitude, the second magnitude, and the fourth magnitude.

12. A method of wirelessly transferring power with a wireless power transfer device having a first transmitter coil, a second transmitter coil, and a repeater coil, the method comprising:

electrically coupling a first power amplifier to the first transmitter coil;

generating a first drive signal with the first power amplifier;

electrically coupling a second power amplifier to the second transmitter coil;

generating a second drive signal with the second power amplifier;

generating, with the first transmitter coil, a first magnetic field having a first magnitude in response to receiving the first drive signal;

generating, with the second transmitter coil, a second magnetic field having a second magnitude in response to receiving the second drive signal;

magnetically coupling the first transmitter coil and the second transmitter coil with a repeater coil; and

combining the first magnetic field and the second magnetic field to generate, with the repeater coil, a third magnetic field having a third magnitude, wherein the third magnitude is greater than the first magnitude and is also greater than the second magnitude.

13. The method of claim **12**, wherein generating the third magnetic field having the third magnitude includes generating the third magnetic field having the third magnitude that is equal to or less than a sum of the first magnitude and the second magnitude.

14. The method of claim **12**, wherein generating the second drive signal includes generating the second drive signal having a phase difference with respect to the first drive signal.

15. The method of claim 14, wherein generating the second drive signal having a phase difference with respect to the first drive signal includes generating the second drive signal having three hundred (330) degrees phase difference with respect to the first drive signal.

16. The method of claim 12, wherein generating the second drive signal includes generating the second drive signal that is synchronized with the first drive signal according to an internal reference clock.

17. The method of claim 12, wherein the first transmitter coil includes a first portion, the second transmitter coil includes a second portion, and the repeater coil includes a third portion and a fourth portion, and further comprising:

overlapping the first portion of the first transmitter coil with the third portion of the repeater coil in a first overlap region; and

overlapping the second portion of the second transmitter coil with the fourth portion of the repeater coil in a second overlap region.

18. The method of claim 17, further comprising:

aligning a first flux concentrator with the first overlap region to concentrate a first magnetic flux of the first magnetic field; and

aligning a second flux concentrator with the second overlap region to concentrate a second magnetic flux of the second magnetic field.

19. The method of claim 18, further comprising spacing the first flux concentrator between the first transmitter coil and the repeater coil to maximize a power transfer, and spacing the second flux concentrator between the second transmitter coil and the repeater coil to maximize the power transfer.

20. The method of claim 12, further comprising:

generating a third drive signal with a third power amplifier;

generating, with a third transmitter coil, a fourth magnetic field having a fourth magnitude in response to receiving the third drive signal; and

magnetically coupling the third transmitter coil with the repeater coil,

wherein generating the third magnetic field includes generating, with the repeater coil, the third magnetic field having a third magnitude that is equal to or less than a sum of the first magnitude, the second magnitude, and the fourth magnitude.

21. A wireless power transfer system comprising:

a wireless power transfer device including:

a wireless power transfer array having:

a first plurality of power amplifiers configured to generate a first plurality of drive signals,

a first plurality of transmitter coils configured to generate a first plurality of magnetic fields, each transmitter coil electrically coupled to one of the first plurality of power amplifiers, each magnetic field being phase aligned to be additively combined with the rest of the first plurality of magnetic fields, and

a first repeater coil magnetically coupled to the first plurality of transmitter coils, and configured to additively combine the plurality of magnetic fields from the plurality of transmitter coils,

wherein the wireless power transfer device is associated with a predetermined power transfer area and a predetermined power transfer distance; and

an external device including a receiver coil magnetically coupled to the first repeater coil and configured to receive wireless power from the wireless power transfer device when the receiver coil is positioned within the predetermined power transfer area and the predetermined power transfer distance.

22. The wireless power transfer system of claim 21, wherein the wireless power transfer device further includes a second wireless power transfer array magnetically coupled to the first wireless power transfer array to increase the predetermined power transfer area and the predetermined power transfer distance, the second wireless power transfer array including a second repeater coil.

23. The wireless power transfer system of claim 22, wherein the second repeater coil is magnetically coupled to one of the first plurality of transmitter coils.

24. The wireless power transfer system of claim 23, wherein the second wireless power transfer array includes:

a power amplifier configured to generate a drive signal, the power amplifier being separate from the first plurality of power amplifiers,

a transmitter coil, separate from the first plurality of transmitter coils, electrically coupled to the power amplifier, and configured to generate a third magnetic field in response to receiving the drive signal.

25. The wireless power transfer system of claim 22, wherein the first repeater coil includes a first plurality of edges defining a perimeter of the first repeater coil, and wherein the first repeater coil is magnetically coupled to the first plurality of transmitter coils at the first plurality of edges.

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